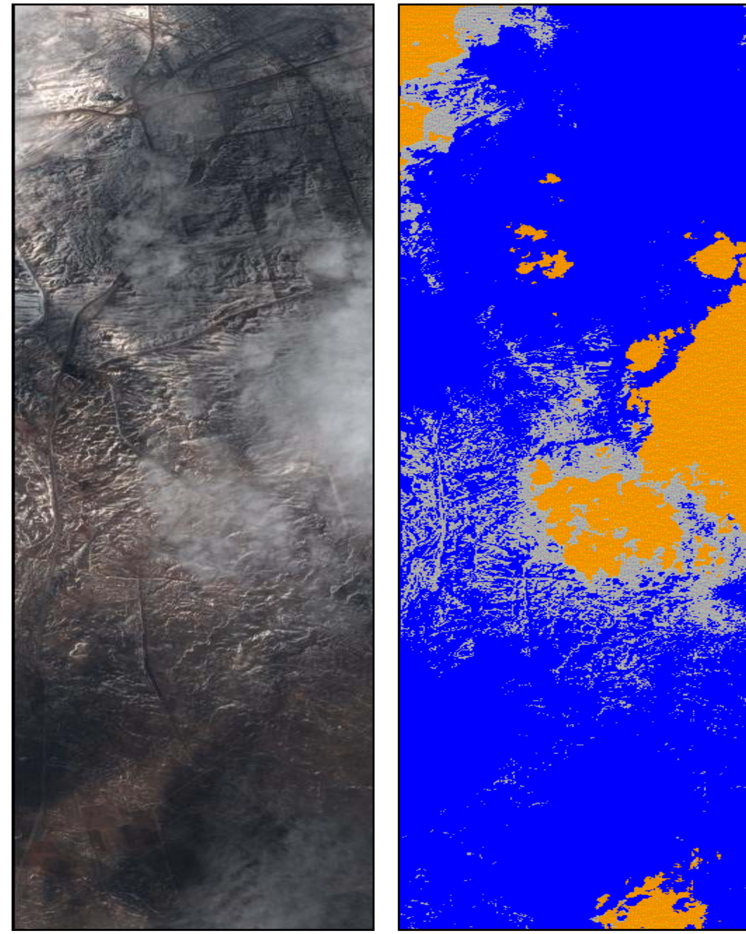
EO-1 Onboard Cloud Cover Detection Validation Presentation

to ESTO Science and Technology Conference



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PI: Dan Mandl/Code 584

Co I: Jerry Miller/Code 586

Michael Griffin/MIT/Lincoln Lab

Team Members

PI: Dan Mandl/GSFC Code 584

Co-I Jerry Miller/GSFC Code 586

Team Members:

Hsiao-hua Burke/MIT-LL

Michael Griffin/MIT-LL

Tom Brakke/GSFC

Stuart Frye/GSFC-Mitretek

Seth Shulman/GSFC-Honeywell

Robert Bote/GSFC-Honeywell

Joe Howard/GSFC-Honeywell

Jerry Hengemihle/GSFC-Microtel

Bruce Trout/GSFC-Microtel

Scott Walling/GSFC-Microtel

Carolyn Upshaw/MIT-LL

Kris Ferrar/MIT-LL

Lawrence Ong/GSFC-SSAI

Larry Alexander/GSFC-Compaq

Nick Hengemihle/GSFC-Microtel

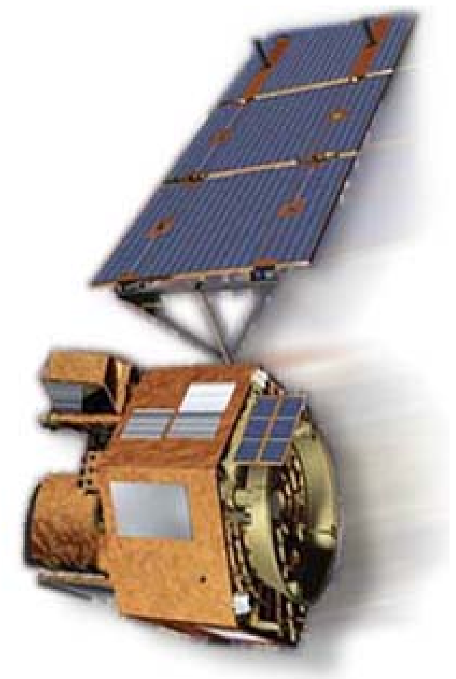
Agenda

- *Introduction & Overview of Activity– Dan Mandl*
- *Cloud Assessment Procedure – Michael Griffin*
- *Conclusion – Dan Mandl*

Introduction to EO1 Mission

- ***Key information:***
  - *Managed by GSFC*
  - *First Earth-Observing Mission sponsored by the New Millennium Program*
  - *A mission devoted entirely to the flight validation of 13 advanced technologies applicable to future land-imaging missions*
  - *Approved in March 1996 and launched in November 21, 2000*
  - *All technologies were flight-validated by December 2001 and EO-1 is now in an Extended Mission*
  - *Sufficient fuel to operate through at least September 2004*

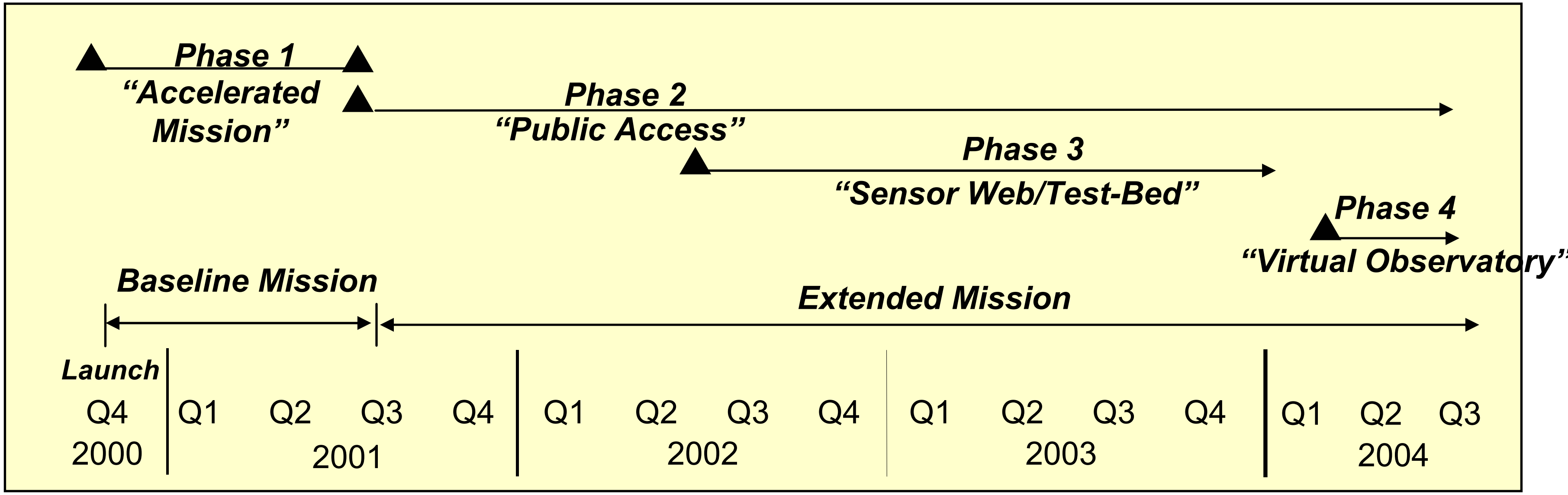
Introduction to EO1 Mission



- ***Payload:***
  - ***Advanced Land Imager (ALI)***
    (visible, 10m resolution)
  - ***Hyperion***
    (hyper-spectral, 220 bands, 30m res.)
- ***Two Mongoose V CPU's (8 MIPS and 256 Mb RAM)***
  - ***Flight control software on CDH CPU***
  - ***Autonomy software (including cloud cover detection software) on Wideband Advanced Recorder and Processor (WARP) Mongoose CPU***

EO-1 Mission Phases

- ***After base mission, three more mission phases evolved as depicted in chart below***
- ***Sensor Web/Testbed phase is active now***
- ***Virtual observatory phase is the phase in which as much mission autonomy as possible will be implemented to reduce the cost as much as possible of running the EO-1 mission***
  - *Includes semi-autonomous tasking of EO-1*



Testing Sensor Web Concepts Using EO-1 as a Testbed

On-board Processing

On-board Cloud Cover Detection Validation

Hyperspectral Compression WG
- ***On-board data mining***
- ***On-board intelligent image compression***
- ***Working group***

Preliminary EO-1 Autonomy Experiment
- ***On-board planning***
- ***On-board feature detection***
- ***Dynamic SW Bus***

End-to-End Communications

Smart Antenna
- ***Ground phased array***
- ***Cell tower com to sat***

Autonomous Coordination

SensorWeb Testbed
- ***Test SensorWeb concepts on ground***

Livingstone On-board Model Based Diag Tool
- ***Autonomous anomaly diagnosis and recommendations***

Operational Testbed

Autonomous Science Experiment(ASE)
- ***Migration of ST6 onto EO-1***

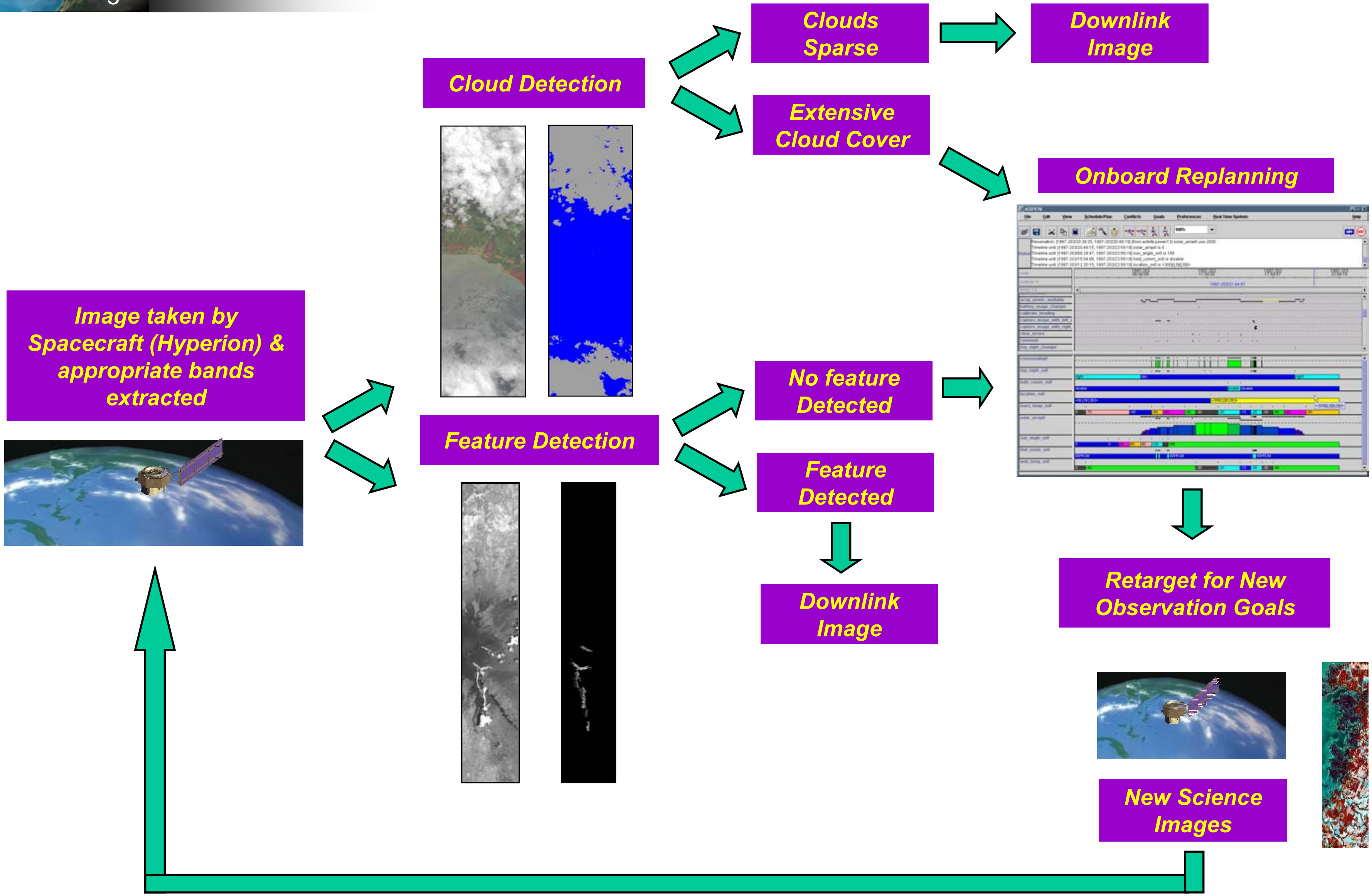
EO-1, Terra, Aqua SensorWeb Demo 1 & 2
- ***Uses MODIS inst center to detect volcanoes***
- ***Uses ASE to coord image collect autonomously***

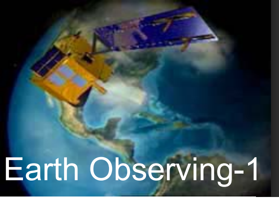
EO-1/ Gnd Sensor SensorWeb
- ***Sensors in Huntington Botanical Garden trigger EO-1 image***

Intelligent Distributed Spacecraft Technology Testbed

Funded by ESTO | ***Funded by NMP*** | ***Funded by RASC*** | ***Proposed activity***

One Target Ops Scenario for Onboard Cloud Cover Scenario





Cloud Cover Assessment Concept

- *Rationale: On board cloud assessment has the potential to considerably reduce the resources on downlink for unwanted scenes.*
- *Concept: Flight validate an onboard cloud cover detection algorithm and determine the performance that is achieved on the Mongoose V*
- *Approach:*
  - ***Formulate and test a cloud cover determination algorithm that is compatible with Hyperion sensor measurements***
  - ***Using MIT / LL provided algorithm, implement and test code to execute on EO-1 platform***
  - ***Uplink and execute code updates onboard EO-1, and evaluate its performance on orbit***
- ***TRL In = 5*** ***TRL Out = 6***

Results

- *Final onboard cloud cover assessment of an EO-1 8 second (.75 Gbyte) Hyperion scene (taken March 4, 2003, El Mhamid) was expected to take hours but instead took less than 30 minutes*
- *Streamlined algorithm by:*
  - ***Performing level 0 on all data and then selecting the needed 6 bands***
  - ***Converted level 0 data to radiance (level 1R) one scan line (256 pixels) at a time***
  - ***Performed pixel by pixel cloud assessment***
- *Can perform onboard cloud assessment faster with the following capabilities:*
  - ***Subsampling of raw data (can get close to same results without processing all data)***
  - ***User defined area of interest within image and only process that portion***
  - ***Direct access to science recorder***
  - ***Cloud assessment algorithm can be expanded since we had more margin than expected***
- *For 20 test cases on ground, performed cloud assessment within 5% for major test cases, final validation underestimated 5-10%*

Cloud Cover Estimation Procedure

Using calibrated Hyperion radiance data, convert to top-of atmosphere (TOA) reflectance and estimate on a pixel-by-pixel basis the extent of cloud cover in a scene.

1. ***Convert Hyperion DNs to Level-1B calibrated radiance data***

   Most complex and time-consuming portion of effort

2. ***Convert radiance data to TOA reflectance***

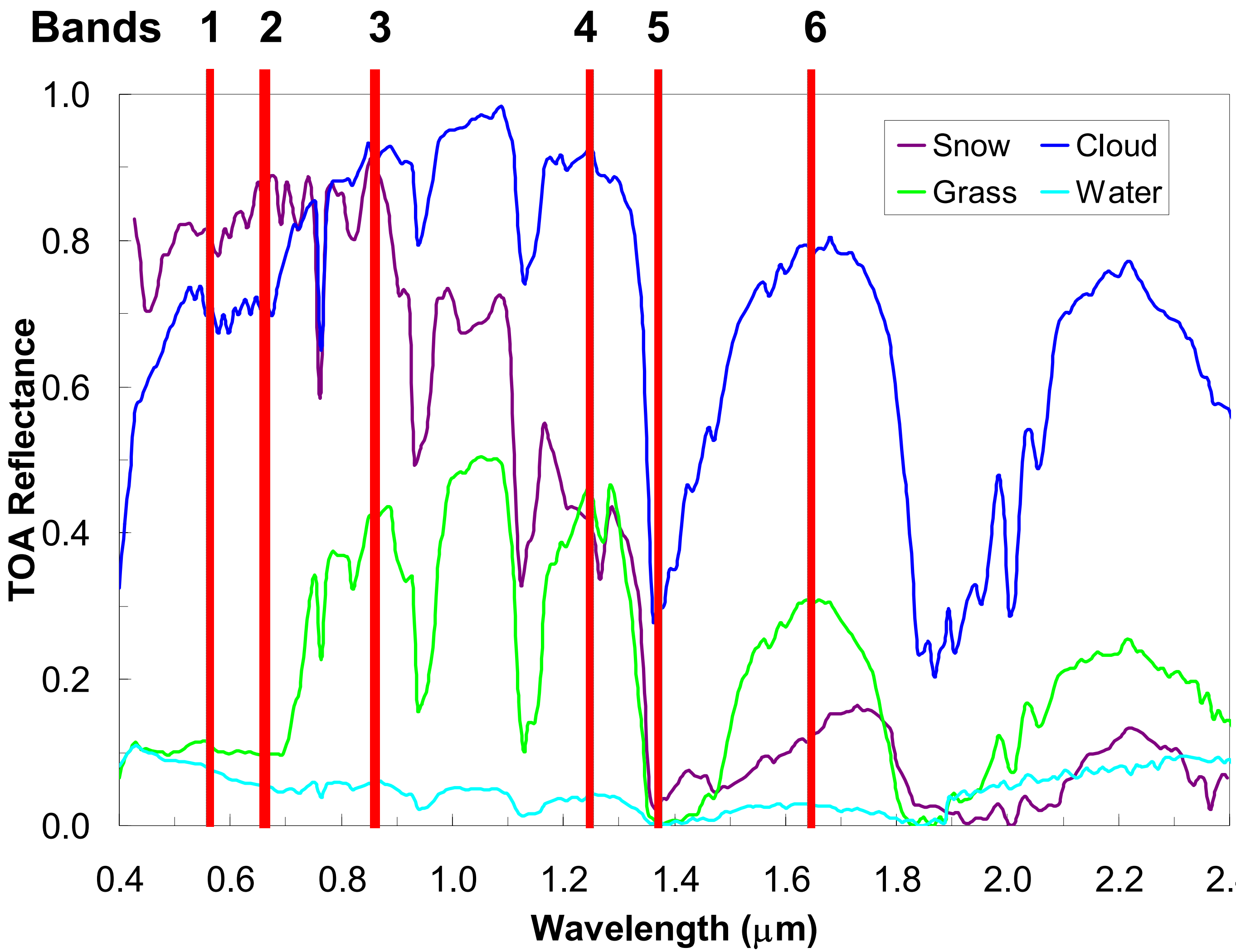
   Use pre-computed band solar flux values, earth-sun distance ratio, and the solar zenith angle

3. ***Process each frame (or line) of data***

   Determine which pixels are cloud-covered
   Distinguish land, water, snow or ice from clouds

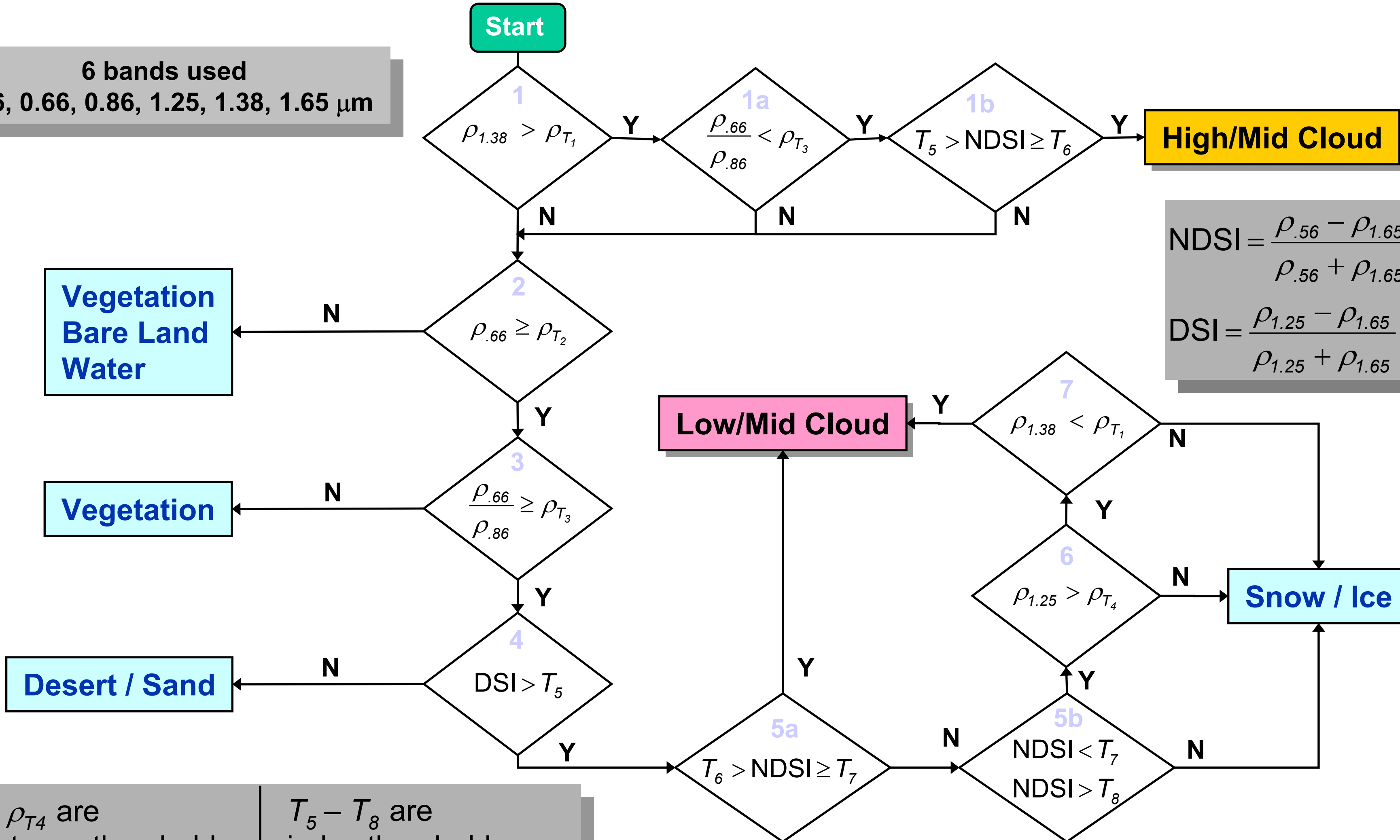
4. ***Produce cloud cover statistics for the scene***

Spectral Band Locations With Sample Reflectance Curves



Cloud Cover Detection Algorithm

6 bands used
0.56, 0.66, 0.86, 1.25, 1.38, 1.65 μm



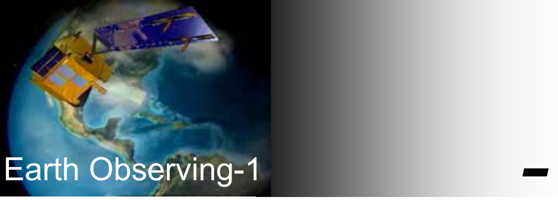
$$\mathrm{NDSI} = \frac{\rho_{.56} - \rho_{1.65}}{\rho_{.56} + \rho_{1.65}}$$

$$\mathrm{DSI} = \frac{\rho_{1.25} - \rho_{1.65}}{\rho_{1.25} + \rho_{1.65}}$$

$\rho_{T1} - \rho_{T4}$ are reflectance thresholds

$T_5 - T_8$ are index thresholds

NDSI: Normalized Difference Snow Index, DSI: Desert/Sand Index



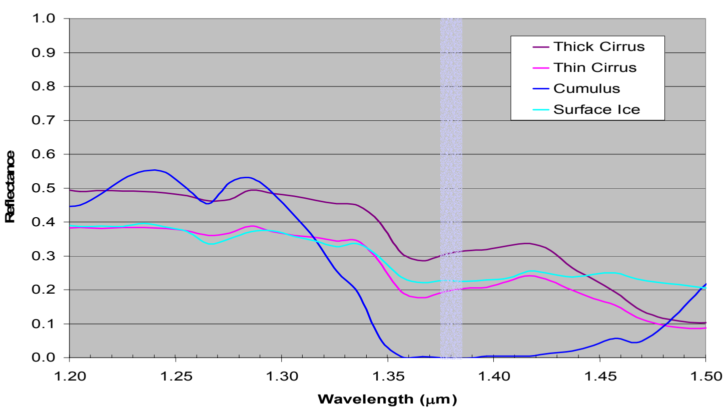
Cloud Cover Algorithm
- NIR Absorption Band Tests -

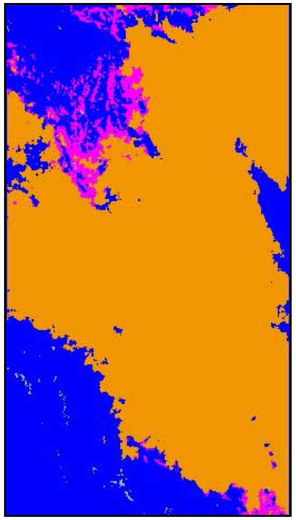
Test 1 : High/mid cloud reflectance threshold

$$\rho_{1.38\ \mu m} > \sim 0.1$$

Cheyenne Wyoming

- ***Only high clouds are typically observed in this channel***
- ***Strong water vapor absorption masks most low level/surface features***
- ***Under dry conditions, surface features such as ice and snow can be observed and mistaken for clouds***
- ***Further vegetation and snow/ice discrimination tests are necessary to isolate clouds***





Cloud-free, Low/Mid cloud, Mid/High cloud

No (N)	Yes (Y)
All others	***High/Mid Clouds***

To Test 2

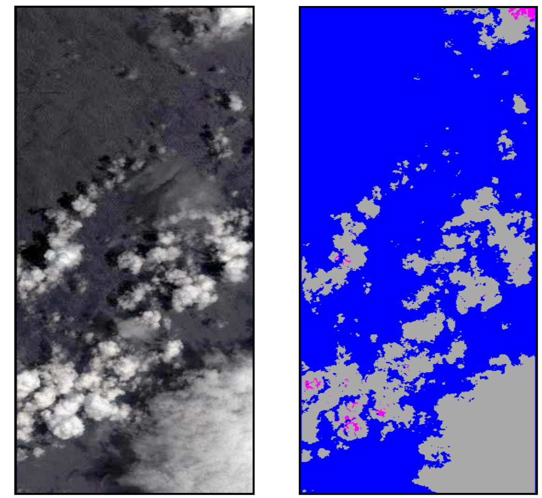
Cloud Cover Algorithm
- Visible Reflectance Test -

Test 2 : Red channel reflectance threshold

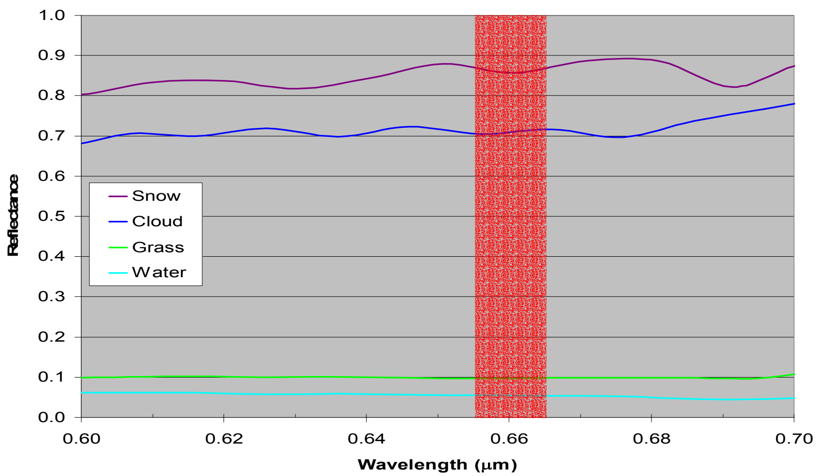
$$\rho_{0.66\,\mu m} > \sim 0.3$$

- *Assumes low reflectance of most vegetation, soil and water surfaces in the red region of the spectrum*
- *Snow, Ice, bright desert/sand surfaces and clouds should pass this test*

Kokee Hawaii



Cloud-free **Low/Mid cloud**



No (N)	Yes (Y)
Vegetation Soil Water	Snow / Ice Desert / Sand Some Vegetation Clouds

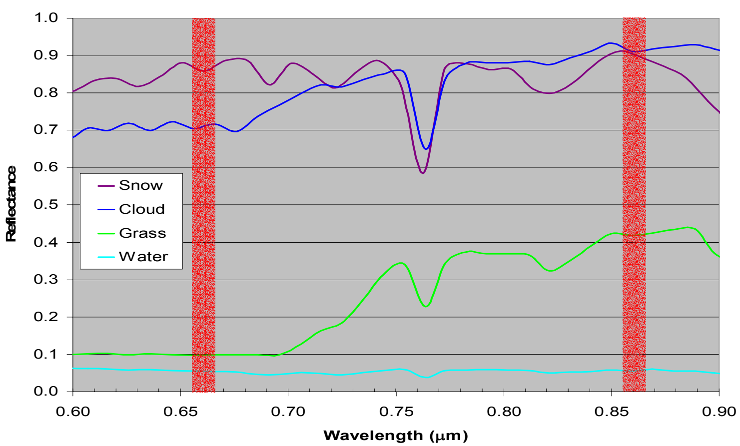
To Test 3

Cloud Cover Algorithm
- Visible/NIR Ratio Test -

Test 3 : VIS/NIR ratio test

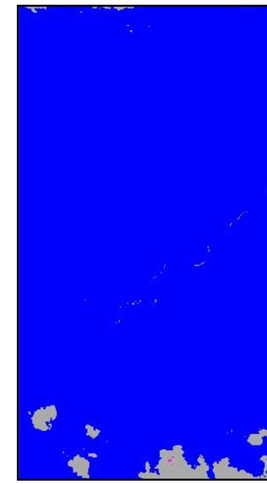
$$\rho_{0.66\,\mu m} / \rho_{0.86\,\mu m} > \sim 0.7$$

- *Discriminates vegetative surfaces whose reflectance varies strongly from Visible to NIR*
- *Vegetative and soil surfaces exhibit small ratio values.*
- *Clouds, desert/sand, snow and ice surfaces have high ratio values*



Kokee Hawaii

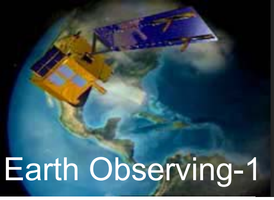
Cloud-free



Low/Mid cloud

No (N)	Yes (Y)
Vegetation	*Snow / Ice* *Desert / Sand* *Clouds*

To Test 4



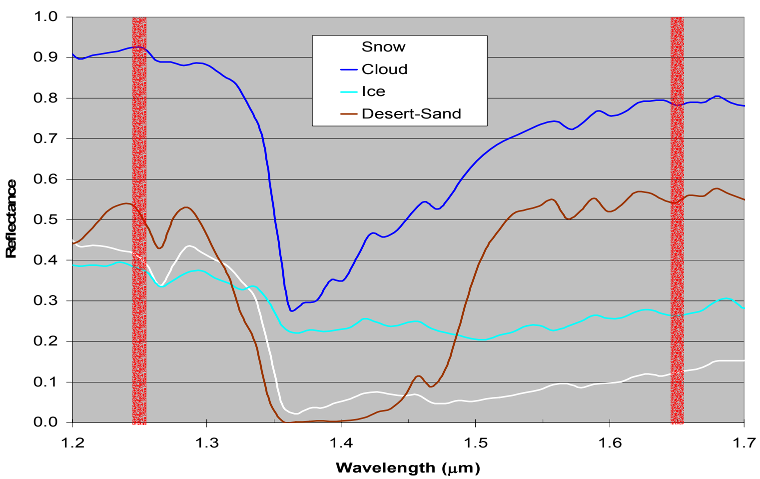
Cloud Cover Algorithm
- Bright Desert/Sand -

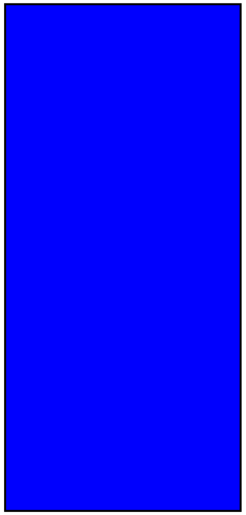
Test 4 : Desert Sand Index (DSI)

Suez Canal

$$\mathrm{DSI} = \frac{\rho_{1.25} - \rho_{1.65}}{\rho_{1.25} + \rho_{1.65}} > -0.01$$

- ***Discriminates bright soil and sand surfaces whose reflectance increases slightly from 1.25 to 1.65 μm***
- ***Clouds, snow and ice reflectance tends to decrease over this range***





Cloud-free

No (N)	Yes (Y)
Desert Sand Bright Soil	*Snow / Ice Clouds*

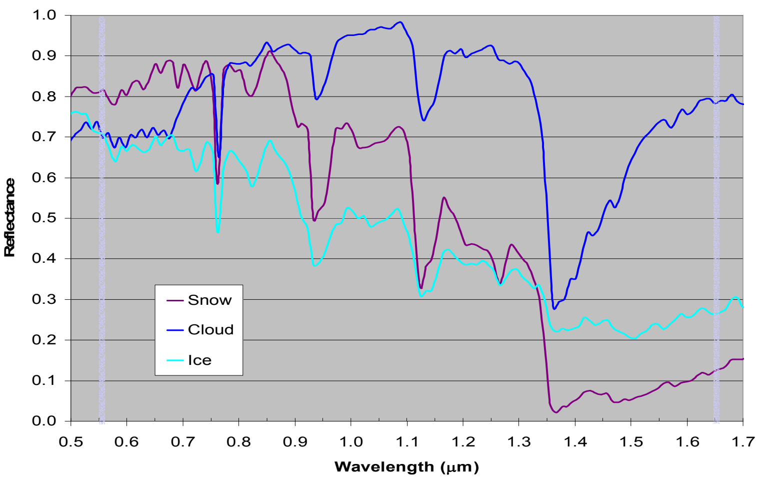
To Test 5

Cloud Cover Algorithm
- SWIR Snow/ice/cloud Test -

Test 5 : Normalized Difference Snow Index (NDSI)

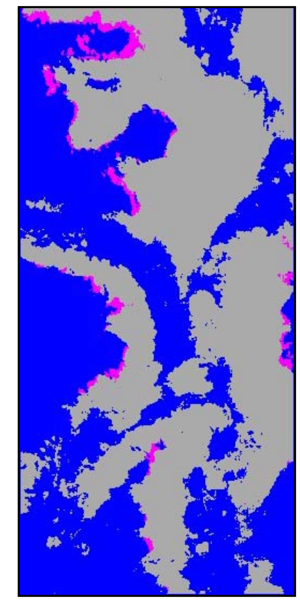
$$\mathrm{NDSI} = \frac{\rho_{0.56\,\mu m} - \rho_{1.65\,\mu m}}{\rho_{0.56\,\mu m} + \rho_{1.65\,\mu m}}$$

- ***Some sparse or shadowed snow (in mountains) can pass test***
- ***Cloud-free snow generally displays NDSI > 0.4***



Sullivan Bay

Cloud-free



Low/Mid cloud

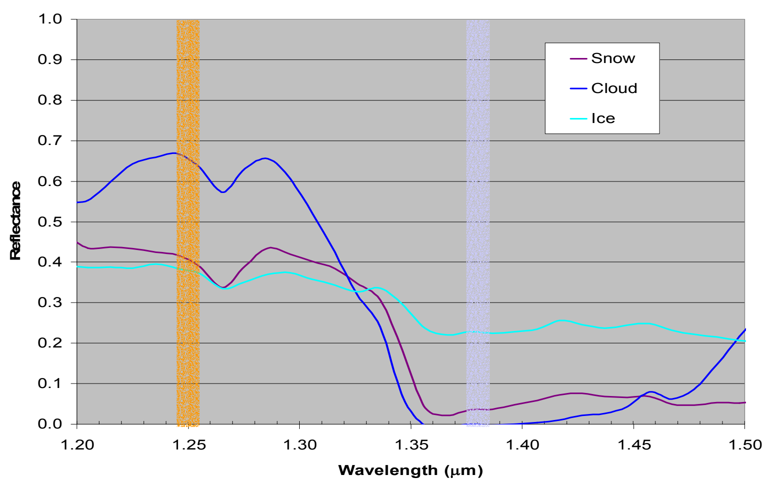
No (N)	*Yes (Y)*
Snow / Ice	***Low / Mid Clouds*** ***Dark Snow***

To Test 6

Cloud Cover Algorithm
- SWIR Reflectance Tests -

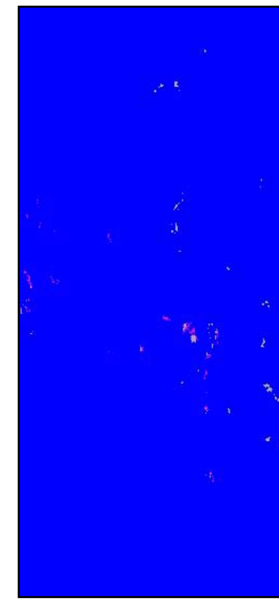
SWIR Reflectance Tests

- ***Test 6*** $\rho_{1.25\ \mu m} > \sim 0.35$
- ***Test 7*** $\rho_{1.38\ \mu m} < \sim 0.1$
- ***Eliminates most snow/ice***
- ***Low/Mid clouds should pass tests***



Bering Sea

Cloud-free



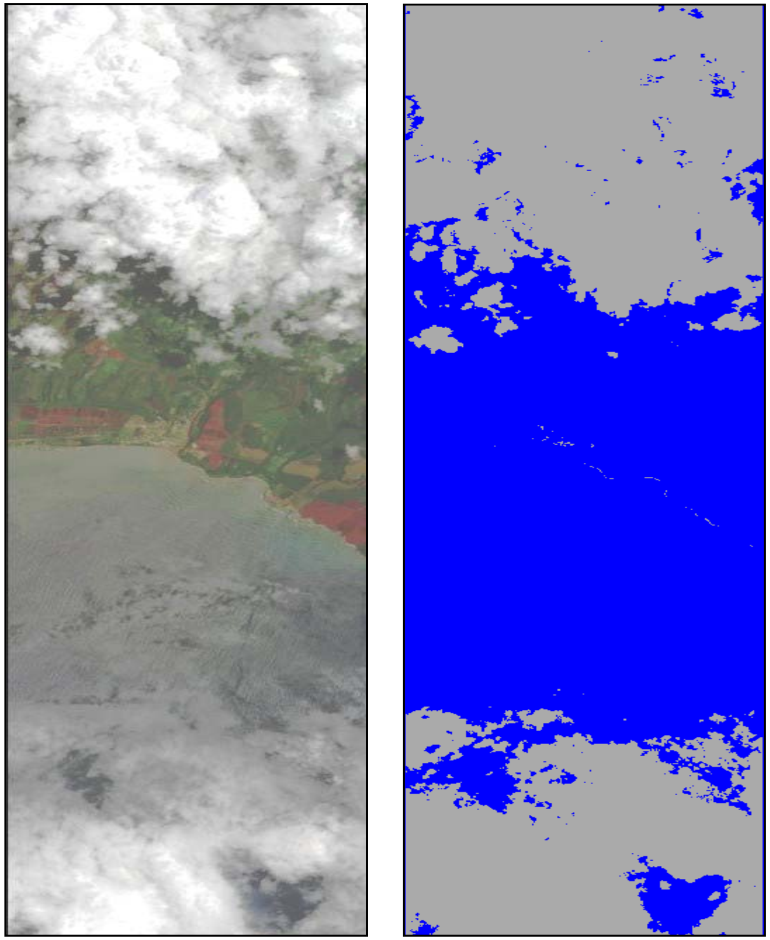
Low/Mid cloud

No (N)	***Yes (Y)***
Snow / Ice	***Low / Mid Clouds***

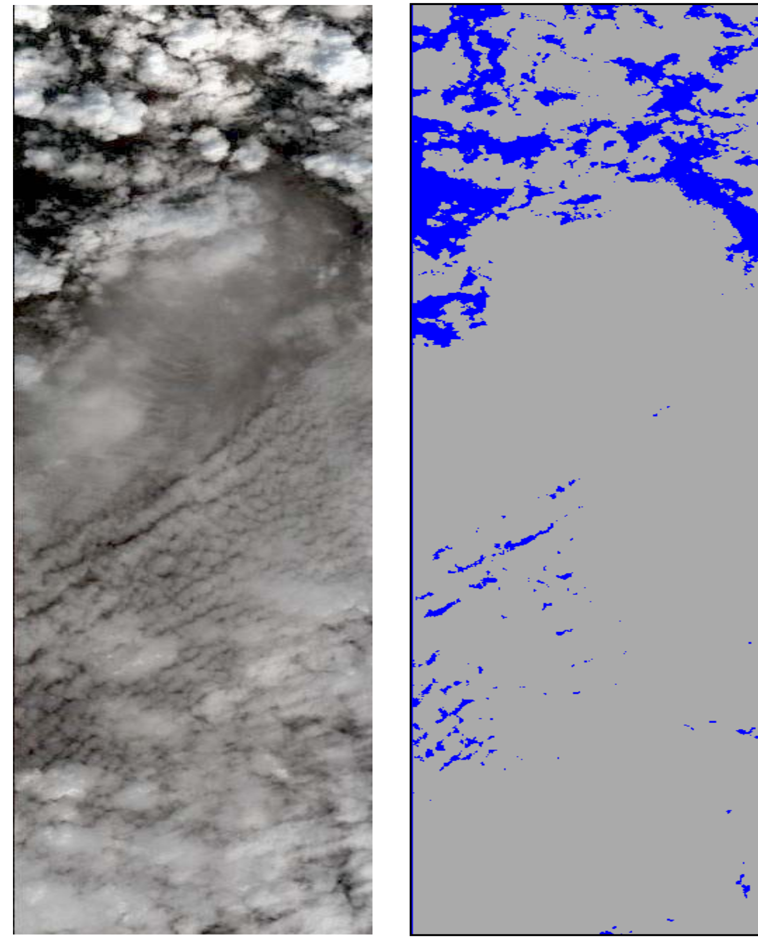
Cloud Cover Algorithm
- Test Case Results -

- ***The following slides show results from the cloud cover algorithm for a selection of Hyperion scenes***
- ***Cloud cover estimates (percent of displayed scene covered by all clouds) is shown at the bottom***
- ***The first on-board cloud cover detection test occurred in March 3, 2003***

Clouds over land and water



Total Cloud: 41.8 %

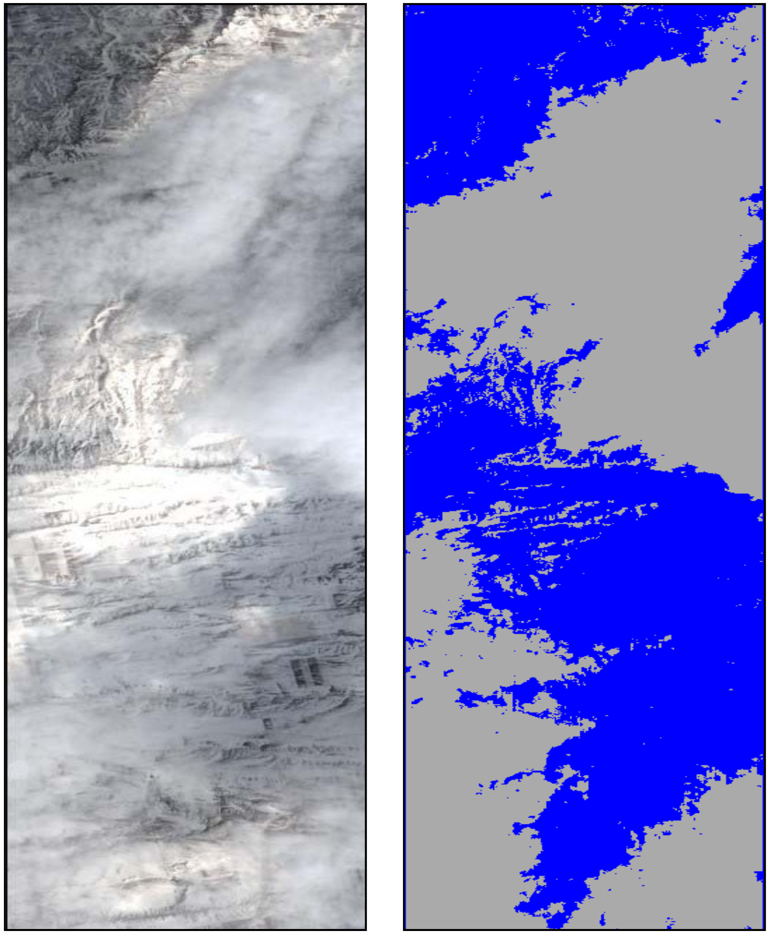


Total Cloud: 89.5 %

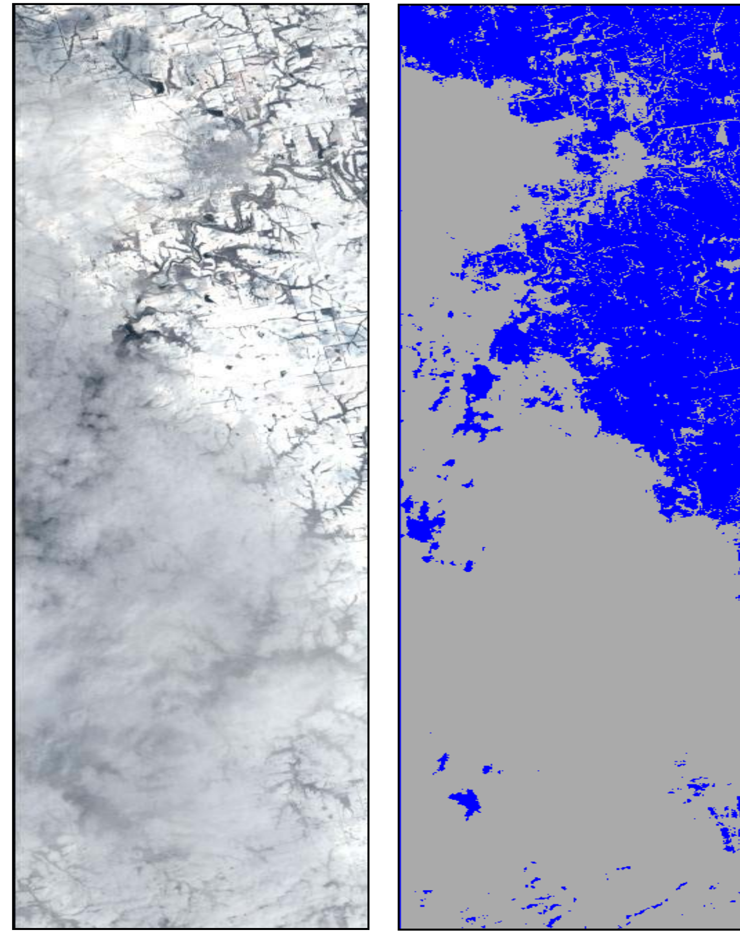
Success	***Discriminates land/cloud, land/water***
Failure	***Misses some darker cloud over water***

Cloud-free
Cloud

Clouds over snow-covered terrain



Total Cloud: 55.0 %

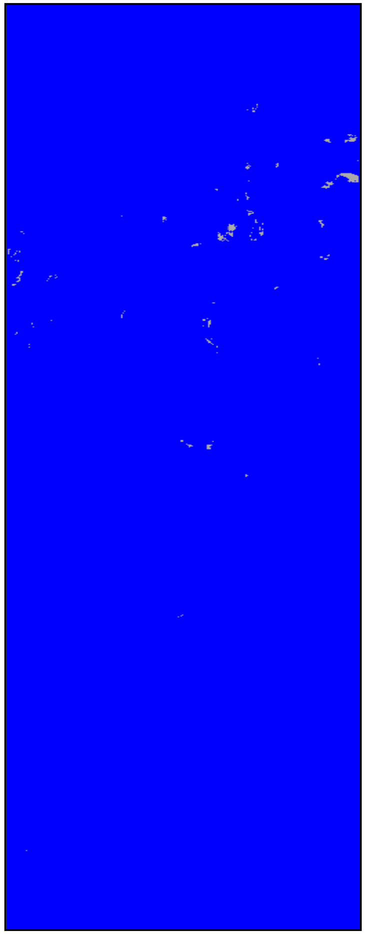


Total Cloud: 69.2 %

Success	***Snow/cloud, ice cloud***
Failure	***Difficulty with shadowed/dark snow cover***

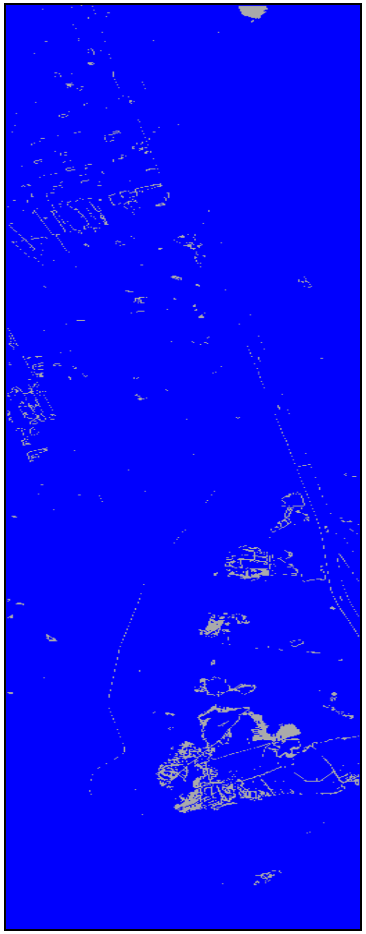
Cloud-free
Cloud

Clear snow/ice covered scene



Total Cloud: 0.2 %

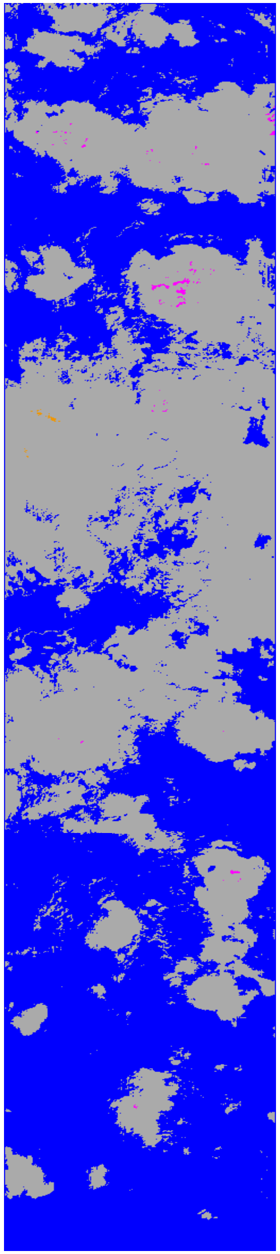
Clear Desert Scene



Total Cloud: 2.2 %

Success	***Bright Ice, snow, sand all flagged clear***
Failure	***Small amount of dark snow/sand features***

Cloud-free
Cloud



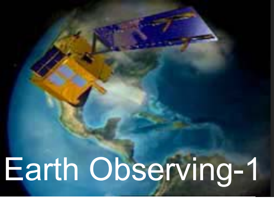
First Hyperion On-board Cloud Cover Test Case

El Mahmid: Path 201 Row 39

- **Observations:**
  - ***The algorithm produced a cloud amount value of 47.1% for this scene***
  - ***The cloud cover for the scene is underestimated by ~ 5 - 10 %***

Summary of Cloud Cover Algorithm Performance

- ***Algorithm results are encouraging***
  - ***Algorithm does well discriminating bright surface features (snow, ice, sand) from clouds***
  - ***Some difficulties with dark snow and dark/shadowed features***
    - *Adjustment of thresholds (e.g., geographical, seasonal) may improve results*
  - ***On-board cloud cover detection accuracy requirements are not stringent (5-10 %)***



Conclusion

- *Discovered many methods to streamline onboard cloud assessment*
- *Big driver to onboard cloud assessment is precision required*
  - ***For many applications, accuracy within 5% is adequate thereby allowing shortcuts***
- *Performance of onboard cloud cover assessment can be tailored to work on lower powered CPU's by using the performance trade space of accuracy, time required to complete, possible use of subsampling of pixels, subsampling of area (area of interest)*
- *Experimenting with onboard cloud detection is a good springboard to continued investigation of the use of onboard feature detection (as is being done in the ongoing sensor web experiments on EO-1)*